NANOFLUIDS CONTAINING ELECTROMAGNETIC NANOPARTICLES: THE REVIEW OF ELECTRICAL PROPERTIES AND APPLICATIONS

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This paper presents a brief review of the electrical properties of nanofluids containing metallic, metallic oxide, graphene nanoparticles, as well as carbon nanotubes. The key factors, such as the alignment of magnetic nanoparticles (NPs), NPs size and shape, surfactants, temperature, base fluid, and NPs types, that demonstrate a significant impact on the electrical properties of nanofluids are analyzed. The applications of nanofluids in transformers (oil, cores, paper impregnation), PVT systems, and hydrogen production are described.

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I General information

One of the most important factors determining the development of society, science, and technology is the efficiency of transmitting and storing energy in any form. Modern methods of energy transport and accumulation have reached such an advanced level that any improvement in their effectiveness is only possible by returning to fundamental research. Nanofluids (NFs), also known as suspensions of nanoparticles in a base fluid (BF), have the potential to become a breakthrough solution due to their significantly better properties, e.g., thermal, optical and magneto-electric, than the conventional macroscopic equivalents of their individual components. In addition, the configuration of nanofluids containing metallic NPs in the volume of a dielectric liquid are almost ideal structures for studying electrical transport, dielectric polarization, and relaxation processes because they allow the study of electric charge transfer both between individual metal NPs and between NPs and large conducting agglomerations.

The paper presents a brief discussion of the electrical properties of nanofluids containing metallic nanoparticles randomly dispersed in different types of BFs, while the greatest attention will be given to the electrical properties and application of NFs in the electrical engineering.

II Nanofluids manufacturing

All NF preparation methods can be divided into two groups: one-step and two-step. In the one-step method, the NPs are produced and dispersed into the BF during the single preparation process. For this purpose in the most cases the physical vapor deposition techniques such as evaporative deposition, laser ablation, magnetron sputtering, etc., that allow to produce uniform NPs are used. The direct evaporation and condensation of NPs are carried out in the BF.

The two-step method relies on first producing the NPs in the form of nanopowder and then directly mixing them with the BF. One of the main drawbacks of this method is NPs aggregation. That's why the common practice to solve the issue is using surfactants during mixing and ultrasonication after the NPs have been initially dispersed. The two-step method is considered to be the most economical and commercial type for large-scale NFs manufacturing. The majority of the different size nanopowders are commercially available and relatively inexpensive in comparison to single-step production.

III Electrical properties of nanofluids

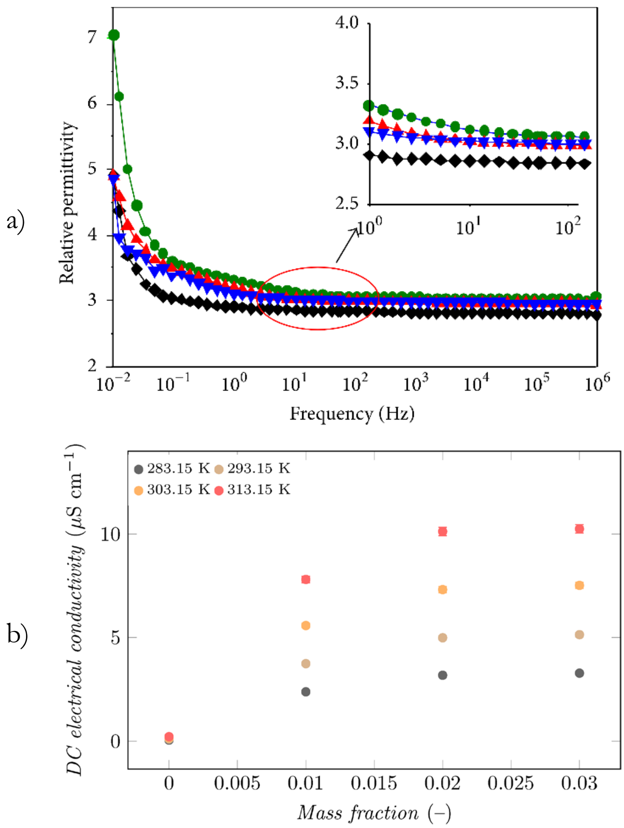

Figure 1: Impact of conductive filler concentration on: a) relative permittivity of vegetable oil-Fe_3O_4 NFs [2]**, and b) DC electrical conductivity of the $CaCO_3$-EG NFs** [3]

Taking into account that the most commonly used nanofillers are pure or/and (hybrid type) oxidized metals, graphene and CNTs, that are conductive ones, including them into the BFs, which normally are dielectric, significantly increases the electrical conductivity of the NF. The literature reports a lot of examples proving this fact. For example, mineral oil-based NFs contained Fe_3O_4 NPs; the resistivity of NF is about 10 times lower than in pure BF, and its dissipation factor rises while the concentration of Fe_3O_4 increases [1].

Another study of Fe_3O_4 NPs in vegetable oil showed that there is an impact of the nanofiller's particle size on the dielectric properties of the NFs [2].

Fig. 1.a demonstrates that an increase in NP size causes an increase in relative permittivity, especially for low frequencies.

Fig. 1.b presents the dependence of the DC conductivity of the $CaCO_3$-EG NFs on the nanofiller's mass fraction, which ranges from 0.01 to 0.03. It can be clearly seen that the conductivity increases with the increase in $CaCO_3$ concentration. The AC conductivity of NFs filled with $CaCO_3$ NPs and measured at different temperatures is more than 10 times higher in comparison to EG, as reported in [3].

The electrical properties of hybrid NFs are strictly dependent on the nanofiller's electric profiles. For example, in case of TiB_2/B_4C NFs based on propylene glycol, the electric conductivity of B_4C NF is at least about 70 times higher than the BF and about 63 times higher than mixed TiB_2 and B_4C NF. Such a situation can be associated with the differences in the conductivities and NP sizes of TiB_2 and B_4C, as it was also founded in EG-based SiO_2/Al_2O_3 hybrid NFs.

Factors that influence the electric conductivity of NFs are not only the types of nanofiller and BF, NPs mass fraction and size variations, but also sonication time (ST) during the production and surfactant/nanofiller mass ratio. ST increases significantly the conductivity when surfactant is added.

IV Selected applications of NFs in electrical engineering

The vast majority of articles describing the use of nanofluids in electrical or power systems concern transformer technologies. A lot of them relate to the improvement of transformer oil with the use of various metal oxides and graphene NPs. For example, a paper [4] reports the influence of the addition of TiO_2 (TO) and exfoliated hexagonal boron nitride (Eh-BN) NPs to the mineral oil (MO) as a base fluid on the AC breakdown voltage (ACBV), dielectric constant, and dielectric dissipation factor (DDF). It was found that nanofiller-contained oil demonstrates a way better ACBV (TO NF, approx. 46 kV, Eh-BN NF, approx. 75 kV) than pure MO (approx. 35 kV). The highest dielectric constant at 90°C was observed in Eh-BN NF, while the least was observed in pure MO. In the case of DDC, an inverse tendency was noted.

The exploitation life of a transformer depends largely on the oil-impregnated paper's insulating characteristics. Research [5] showed that the maximum AC breakdown voltage of Fe_3O_4 NF-impregnated paper is 9.1% higher than that of pure oil-impregnated ones. The situation is similar in the case of DC breakdown voltage; its value increases by about 10.0% in comparison to just oil impregnation. However, paper impregnation by NF with conductive NPs leads to an increase in electrical conductivity and dielectric loss afterwards, which should be taken into account when power equipment is designed.

NFs can also find applications in cooling systems for photovoltaic thermal (PVT) systems [6]. Egyptian scientists conducted research on traditional polycrystalline solar panels simultaneously under the same weather conditions for three experimental arrangements: the first module was a reference; the second was water-cooled; and the third module was cooled by a mixture of water and Al_2O_3 NPs (only 0.05% volume concentration). They examined the electrical conversion efficiency in relation to the coolant used. It was discovered that the use of active Al_2O_3 NF cooling causes the biggest drop in PVT operating temperature (about 22.83%), which is crucial for the PV panel performance. This fact corresponds to the obtaining of the highest value of electrical efficiency of about 12.94% by the third module, while the efficiencies of the second and first modules are 12.53% and 11.99%, respectively.

NFs are beginning to be increasingly investigated for hydrogen production in the PVT panels through the electrolysis process. During the electrolysis, the water splits into hydrogen and oxygen, while the first is separated and stored. Adding graphene or CNTs (i.e., carbon black with concentrations of 0.01 wt%~0.3 wt%) to water can significantly enhance hydrogen production, even up to 23.62% in comparison to pure water, as reported in [7].

V Conclussions

Nanofluids containing metallic, metal oxide, graphene, and carbon nanotube nanomaterials demonstrate great application potential in not only heat transfer technologies but also in systems, the main issues of which are the insulating properties of electric or power devices, cooling systems for PV panel efficiency enhancement, PV energy conversion, energy and hydrogen storage systems, etc. If the key factors of the thermal properties of NFs, such as the alignment of magnetic NPs, NP size and shape, pH of the base fluid, surfactants, solvents, and hydrogen bonding, temperature, base fluid, and NP types, are studied at an advanced level, the influence of these parameters on their electric properties and dielectric performance needs more in-depth investigation. This will allow for the creation of more energy-efficient technologies for sustainable energy development as well as technologies that are friendly to the natural environment and ecology.

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